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Cruft Laboratory
Harvard University
Cambridge, Massachusetts

PROGRESS REPORT NO. 39

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COVERING PERIOD
JANUARY 1, 1956 – APRIL 1, 1956

Contract N5ORI-76
Task Orders 1 and 28

April 1, 1956

Cruft Laboratory

Harvard University

Cambridge, Massachusetts

Progress Report No. 39

Covering Period

January 1, 1956 – April 1, 1956

The research reported in this document, except as otherwise indicated, was made possible through support extended Cruft Laboratory, Harvard University, jointly by the Navy Department (Office of Naval Research), the Signal Corps of the U. S. Army, and the U. S. Air Force, under ONR Contract N5ori-76, T.O. 1 and 28. Related researches supported by the U. S. Air Force Cambridge Research Center under Contracts AF19(604)-786 and AF19(604)-1084, or by the University, are also reported briefly with appropriate special acknowledgment.

Task Order 1 NR-372-012	Submitted by The Steering Committee
Task Order 28 NR-372-011	Submitted by H. R. Mimno
Air Force Contract AF19(604)-786	Submitted by R. W. P. King
Air Force Contract AF19(604)-1084	Submitted by C. L. Hogan

April 1, 1956

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I

ELECTROMAGNETIC RADIATION, MICROWAVE CIRCUITS AND RANDOM PROCESSES*

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Dr. G. Kent
Dr. R. V. Row

I-A Antennas

I-A-1 Experimental Study of Transverse Field Distribution and Driving-Point Impedance of Complementary (Slot) Loop Antennas, T. Kaliszewski.

Objective — To study the transverse electric field distributions on complementary slot circular and square loops at 10 cm.

Practical Significance — The application of Babinet's principle permits the determination of the distributions of current in practically important wire antennas.

Status — This work is completed and a technical report is in press.

I-A-2 Slot Transmission Lines, G. Owyang.

Objective — To study the properties of the slot equivalent of a two-wire line.

Status — The construction of probe equipment is completed. Preliminary measurements indicate a more precise detecting system is necessary. Different detecting systems are being tried.

I-A-3 Propagation of Electromagnetic Waves into Conducting Dielectrics, A. Jayne.

Objective — To study the propagation of electromagnetic waves into conducting dielectrics and to study the circuit and field properties

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*Project 1 unless otherwise indicated.
**On leave of absence.

of antennas for transmission into conducting dielectrics.

Practical Significance — Electromagnetic prospecting, underground and underwater radiating systems and the transmission of radio signals into the upper atmosphere are all practical problems which require a knowledge of the propagation of electromagnetic waves into conducting dielectric media.

Status — The experimental work is being delayed due to the necessity of relocating the tank and associated measuring equipment from inside the penthouse to a platform on the roof of the Laboratory. This was considered necessary as a safety precaution, since the large volume of liquids being used constitutes a fire and health hazard in view of their inflammability and toxicity.

I-A-4 Antennas in and over Imperfect Dielectrics, S. Stein.

Objective — To study the properties of antennas when immersed in or placed near conducting dielectrics.

Practical Significance — Propagation over the earth, into the earth, and from one underground location to another, as well as the exploration of the earth by electromagnetic methods, requires a knowledge of the circuit and field properties of antennas near and in the earth.

Status — Technical Report 226 is in press.

I-A-5 The Long Antenna, T. T. Wu, P. Kennedy.

Objective — To study the properties of linear antennas that are several wavelengths long.

Practical Significance — There are practically no data available for antennas that are more than two wavelengths long.

Status — It has not been possible so far to carry out machine computations of the current distribution.

The experimental phase of the work is expected to start in May. Input impedance and current distributions on long antennas (of the order of 20 wavelengths) will be measured. Antennas rigidly supported horizontally on the roof of Gordon McKay Laboratory will be fed from a balanced two-wire line with an 825 Mc/s, 4-watt signal source. An internal probe will be used to measure the current distribution. The same signal source and internal probe will be used with vertical antennas mounted over the large ground plane on the penthouse. A good check on the validity of the measurements will be provided if the results can be duplicated with vertical antennas.

I-A-10 Antenna Measurements on the Image-Plane Line, P. Kennedy, S. Prasad.

Objective — The research in this project is directed toward the general study of various types of antennas driven by an image-plane line.

Practical Significance — In order to provide complete data on the behavior of various types of antennas not applicable to coaxial-line techniques and to verify theoretical studies, experimental measurements are required.

Status — Refer to I-A-11.

I-A-11 Experimental and Theoretical Study of Loop Antennas, S. Prasad.

Objective — General study of the properties of square-loop antennas.

Practical Significance — A square loop which may be large compared to the wavelength is known to have useful properties in numerous special cases such as the square rhombic, direction-finders, etc. A general study of its circuit field properties when driven or loaded at one or more points around its perimeter should provide data to extend its usefulness.

Status — Input impedances of a large square loop loaded at one corner with pure resistances were measured and a relation to corresponding transmission-line impedances was sought. No definite conclusions were reached. Square loops driven by voltages that are in phase opposition and located at diagonally opposite corners are now being studied.

I-A-16 Transient Characteristics of Antennas, R. Long, R. V. Row.

Objective — To investigate theoretically and experimentally the receiving and transmitting behavior of various antennas when subject to pulse excitation.

Practical Significance — An understanding of the transient behavior of simple antennas will be of value in the practical design of large directive antennas for radar.

Status — A solution to the problem of a suitable pulse potential divider is still being sought.

I-A-17 Single Conductor Lines over Coated Conducting Planes, C. Shafer.

Objective — Theoretical and experimental investigation of single conductor lines over conducting planes coated completely or partially with dielectric.

Practical Significance — Recently developed and commercially used microwave-strip circuits involved such lines.

Status — Comparison of the TEM mode field distribution with the field distribution of the microstrip mode has been made. The similarity of the transverse fields is quite close, differing only by the perturbation due to the presence of the dielectric. An integral equation for the current on the strip was obtained utilizing the Green's function for a horizontal dipole over a coated conducting plane. The integrations involved are formidable, even for the case of the constant current transverse distribution on the strip. The integrals do present the possibility of a series solution, and this is being pursued.

I-B Microwave Optics

+I-B-4 Back-scattering Measurements, R. V. Row.

Objective — The research in this project is directed toward the general study of back-scattering.

Practical Significance — A rapid and accurate method for measuring back-scattering from arbitrary obstacles is useful in determining radar cross sections.

Status — No progress this quarter. Additional staff is being added to this project with the hope of completing the work this quarter.

+I-B-6 Pulse R-F Back-scattering Measurements, C. Tang.

Objective — To use close-range radar techniques to make accurate back-scattering cross section measurements of obstacles of arbitrary shape.

Practical Significance — This method is expected to yield a high degree of accuracy in measuring small back-scattering cross section, since the scattered field is not mixed with incident field in time.

Status — Temporarily inactive.

I-B-9 Unflanged Semi-infinite Rectangular Guide, M. Balser, R. V. Row.

Objective — To investigate the frequency dependence of the dominant-mode reflection coefficient from the open end of an unflanged rectangular guide.

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+Air Force Contract AF19(604)-786.

Practical Significance — An experimental measurement of this quantity is necessary as a check on an approximate theory for a previously unsolved problem.

Status — Computations are nearing completion.

+I-B-20 Theory of Electromagnetic Corrections to Geometrical Optics, R. D. Kodis.

Objective — The development of asymptotic expansions for scattering at high frequencies through the application of variational principles.

Status — Examination of the integration process by which the variational correction to geometrical optics is evaluated in scattering by a circular cylinder shows that the principal contribution comes from a small region near the shadow boundary. The remainder of the cylinder has a negligible effect and can be of any shape, provided (1) that its radius of curvature is positive in the shadow neighborhood, (2) that its projected cross section is large compared to the wavelength, and (3) that the "equivalent strip" is normal to the direction of incidence. For such an obstacle all that is required to calculate the correction to its cross section is a knowledge of the radii of curvature R_1 and R_2 at each shadow boundary. (Fig. I-1.) One can

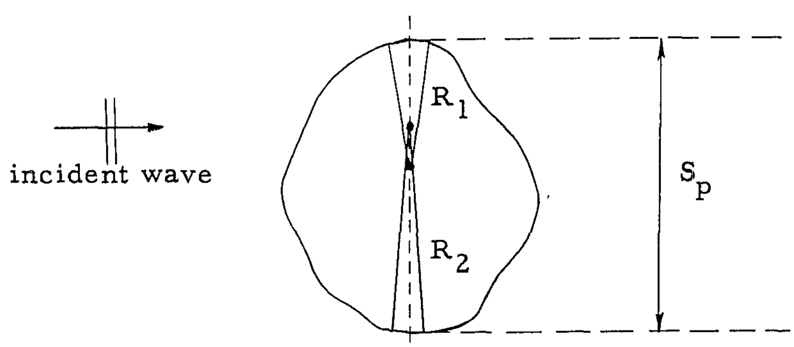

Fig. I-1

replace the actual obstacle first by a circle of radius R_1 and then by a circle of radius R_2. The contribution to the correction from the shadow near R_1 will be half that for the corresponding circle, and similarly for R_2. Thus using the results for the circle, the correction in the Dirichlet case is

$$\sigma' = \frac{1}{k} \operatorname{Im} A' = 2c[R_1^{1/3} + R_2^{1/3}]\, k^{-2/3},$$

where c is the numerical coefficient for a circle. The total cross section normalized to the geometric optics value, $2S_p$, is

$$\frac{\sigma}{2S_p} = 1 + \frac{c}{S_p k^{2/3}}[R_1^{1/3} + R_2^{1/3}] .$$

In the case of the ellipse shown in Fig. I-2 the radius of curvature at

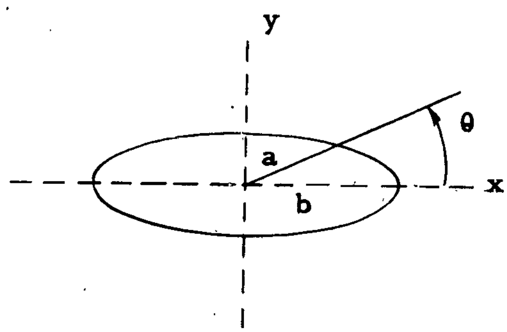

Fig. I-2

the shadow boundaries is given by

$$R = \frac{b^2}{a}(\sin^2 \phi + \frac{a^2}{b^2} \cos^2 \phi)^{3/2} .$$

The ellipse is described by the equation

$$(\frac{x}{b})^2 + (\frac{y}{a})^2 = 1 ,$$

and the angle ϕ is defined in terms of the usual polar angle θ by the transformation,

$$\tan \phi = \frac{b}{a} \tan \theta .$$

If the shadow boundaries are at $\phi = \pm\frac{\pi}{2}$ the illumination is in the direction of the major axis and a straightforward calculation shows that*

$$\frac{\sigma}{4a} = 1 + 0.498(1-e^2)^{-1/3} (ka)^{-2/3} + \dots ,$$

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*The numerical coefficient is taken from the result calculated by Wu and Rubinow (Cruft Laboratory Scientific Report No. 3, AFCRC-TN-55-560).

where $e^2 = 1 - (a/b)^2$. On the other hand, when the illumination is along the minor axis with the shadow boundaries at $\phi = 0$ and π,

$$\frac{\sigma}{4b} = 1 + 0.498(1-e^2)^{1/3}(kb)^{-2/3} .$$

It should be noted that for the first result the limit e = 1 is excluded since it does not satisfy the condition $ka >> 1$. In the second result, however, kb may be large even if e = 1. For this case the correction is zero to order $(kb)^{-2/3}$ in the limit, and we must revert to the high-frequency theory for a strip.

If $0 < \phi < \frac{\pi}{2}$, the equivalent strip is not normal to the incident direction and the possibility of interference effects between the two shadow boundaries must be taken into account.

+I-B-24 The Scattering of Plane Waves by Obstacles, S. I. Rubinow, T. T. Wu.

Objective To obtain a theoretical correction to geometrical optics for scattering of plane waves by spheres at high frequencies.

Status For the scattering of a plane wave by a dielectric sphere, the Bessel functions in the coefficients of the infinite series for the scattering amplitude may be replaced by their asymptotic expansions for large values of ka. This leads to a geometric-optical identification of terms as representing the externally reflected ray, transmitted ray, once internally reflected ray, and so forth, according to the multiplicity of the internal reflections [1]. For values of the index of refraction N close to unity, the first two mentioned terms are the most important for determining the scattering amplitude. In particular, the transmitted ray leads to the van de Hulst [2] (or Glauber) approximation. The reflected ray, at grazing incidence, yields a first correction term to the total cross section which is identical with that for the infinitely conducting sphere (of order $(ka)^{-2/3}$).

+I-B-25 The Scattering of Plane Waves by Conducting Obstacles at High Frequencies,* L. Wetzel.

Objective To obtain, by variational methods, approximations to the total cross section for scattering of plane electromagnetic waves by perfectly conducting obstacles of complex shape.

Status During the last reporting period the variational half-space formulation, in which the problem is envisaged as two half-spaces coupled by a fictitious surface through the obstacle, was studied

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[1] P. Debye, Ann. der Physik 30, 57 (1909).
[2] H. C. van de Hulst, Recherches Astron. de l'Observatoire d'Utrecht 11 (1946).
*Formerly Project I-B-28.

in greater detail. Using the usual optical approximation to the currents on the obstacle and assuming the incident wave to be unperturbed on the fictitious surface (a trial function that fails to satisfy the boundary conditions at the obstacle), application to a spherical scatterer was unsuccessful. Attempts to correct the trial function on the fictitious surface by including the field scattered across it by the obstacle led to formidable complications. In an effort to determine whether there was anything still to be gained from the conventional variational formulation (obstacle in free space), attempts were made to do the characteristic surface integrals exactly. The results, though suggestive, were inconclusive.

In reviewing the simpler scalar problems, certain anomalous results were noted. These are being studied at the present time.

+I-B-26 Scattering on Cylindrical Objects at High Frequencies, F. E. Borgnis.

Objective The scattering of conducting cylindrical objects is being studied with special consideration of very high frequencies of the impinging wave, that is, at large values of $ka = 2\pi\ a/\lambda$ (a = linear dimension of the cylinder cross section).

Status Further investigation has been carried on of various methods for obtaining the scattered field and the scattering cross section of metallic obstacles at very high frequencies.

I-B-27 Propagation of Slow Electromagnetic Waves, F. E. Borgnis.

Objective A general study of slow wave propagation.

Status The general aspects of slow wave propagation along cylindrical metallic or dielectric structures by means of an idealized boundary condition of the type $\partial u/\partial n + \sigma u = 0$ have further been pursued and their application to a number of special examples is under study.

+I-B-28 Back-scattering from a Dielectric-coated Infinite Cylinder,* C. Tang.

Objective Theoretical and experimental investigation of back-scattering behavior from an infinite conducting cylinder coated with a dielectric layer is being undertaken.

Practical Significance The scattering property of a scatterer usually can be varied or controlled by coating it with a dielectric layer of suitable dielectric constant and appropriate thickness.

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*Formerly Project I-B-29.

Status The construction of the parallel-plate region with rotating discs has just been completed and measurements will be undertaken very soon. The dielectric constant of the dielectric materials to be used will vary from 2.56 to 20 with very low loss. Part of the computation from the theoretical investigation has been completed and computation is still in progress.

I-C Microwave Circuits

++I-C-1 Properties of Ferrite Materials, C. L. Hogan and J. Pippin.

Objective To measure and correlate the macroscopic properties of ferrites with intrinsic parameters such as crystalline anisotropy, magneto-elastic anisotropy, saturation moment, ferromagnetic resonance line width, etc.

Practical Significance In order to extend the practical frequency range and power level of various microwave ferrite devices a more detailed and quantitative knowledge of the properties of ferrites is needed. This will be obtained from these studies.

Status A five-string pendulum magnetometer has been constructed; this device will be used for measuring the saturation moments of the ferrites to be used in the study of the permeability spectrum.

Instrumentation for the permeability measurements is being extended from 2000 Mc/s downward to 10 Mc/s. Thus the experimental set-up for measurement in the 10 Mc/s to 10,000 Mc/s range is virtually complete.

++I-C-2 Microwave Resonance in Highly Anisotropic Ferromagnetic Single Crystals, J. O. Artman.

Objective To study microwave resonance in highly anisotropic ferromagnetic single crystals.

Status The program has been broadened to include ferromagnetic metals as well as ferrites. The theory of the microwave resonances expected from simple multi-domain structures has been extended to metals. The results are similar to those found previously for non-conductors [1] except that the ratio of skin-depth to domain width also becomes an important parameter. The microwave studies will be correlated with d-c measurements to be made by E. R. Czerlinsky of AFCRC, who will also prepare some of the samples. Ni metal single crystal samples used by K. H. Reich are available. Instrumentation is continuing.

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1. J. Smit and H. G. Beljers, Philips Res. Rep. 10, 113 (1955);
T. Nagamya, Prog. Theo. Physics (Japan) 10, 72-82 (1953);
J. O. Artman, Phys. Rev. 100, 1243 (A) (1955).

I-C-4 Broad-Band Microwave Isolator, C. L. Hogan.

Objective To build a broad-band microwave isolator to operate at X-Band frequencies.

Status This project has been temporarily suspended.

I-D Electronics

I-D-1 Investigation of a Modified Type of Barkhausen-Kurz Oscillator, G. Kent, W. Simon.

Objective To investigate the potentialities as a microwave power source of a Barkhausen-Kurz (B-K) tube which is especially designed to provide simple harmonic electron motion and to use efficiently the B-K energy-conversion process.

Practical Significance It is believed that a relatively high-efficiency microwave generator with frequency limitations comparable to those of the reflex klystron might be developed.

Status From cold test data on model cavities, a new single-cavity S-band tube (model IV) has been designed and is currently being constructed. The resonant cavity is expected to have an (R/Q) figure of the order of ten and an unloaded Q greater than 2,000.

The model III S-band tube has been reprocessed to permit further testing. A sharp oscillation at 20 cm has been observed. This is the first evidence of oscillation at a frequency for which the distribution of electric and magnetic fields is relatively simple. The problem of efficient coupling to this oscillation mode remains.

The 500 to 1,000 Mc/s tube has been assembled, and satisfactory cold tests have been completed. Difficulty with the filament structure when hot has necessitated a revised design of filament supports.

I-D-3 Space-Charge-Wave Oscillations in the Magnetron, J. Osepchuk.

Objective The experimental and theoretical study of space-charge waves in the magnetron diode.

Practical Significance The existence of space-charge waves in the magnetron diode is significant in considering low-current behavior in multicavity magnetrons and would indicate the possibility of its use as a microwave signal generator.

Status No progress to report.

I-D-4 Electrolytic Tank, P. Kennedy, G. Kent.

Objective — Design and construction of an electrolytic tank and associated apparatus.

Practical Significance — The electrolytic tank is useful in solving Laplace's equation for two-dimensional problems or three-dimensional problems with axial symmetry such as those which occur in electron optical systems and other electron devices.

Status — Writing of a technical report is almost completed.

I-D-12 Frequency Response of Linear Systems, T. T. Wu.

Objective — To study the behavior of general linear passive input-output systems, including microwave circuits.

Practical Significance — An understanding of the analytical foundations of such systems is a necessary prerequisite to the synthesis of microwave circuits.

Status — A rather subtle error in the earlier work was recently found and corrected.

I-E Random Processes

I-E-5 The General Theory of Reception of Signals in Noise, D. Van Meter.

Objective — By formulating the reception problem in its most general terms this research seeks to show how detection and extraction of signals may be distinguished operationally in a manner independent of arbitrary criteria of performance, and to indicate what methods of modern statistical analysis are to be used in determining optimum performance of receiving systems.

Status — Technical Reports 215 and 216, terminating this project have been issued.

I-E-6 Study of Output Spectra of Several Nonlinear Devices when Fed by Narrow-Band Noise Plus an Unmodulated Carrier, G. Fellows.

Objective — Experimental verification of Middleton's theory on the subject, and an investigation of the problems of spectral analysis.

Status — Technical Report No. 229, terminating this project has been issued.

I-E-7 Experimental Investigation of the Statistical Properties of Noise and Signal Waves in FM Receivers, H. Fuller.

Objective To extend, by experimental measurements, the theoretical results of Middleton to cases of non-ideal receiver models that are impractically difficult to treat analytically.

Practical Applications The signal-to-noise ratio at the output of the receiver as a function of the several design parameters of an FM receiver will be determined. Together with the signal spectrum distortion this information should allow a closer approach to an optimum receiver design for a specific purpose.

Status A technical report is in preparation.

I-E-8 Sequential Detection of Signals in Noise, J. J. Bussgang.

Objective To study the application of sequential probability ratio tests to the problems of detection of signals in noise.

Status Technical Report No. 175, terminating this project, has been issued.

I-F Analysis and Synthesis of Active Circuits

I-F-1 Analysis and Synthesis of Nonlinear Feedback Systems, J. A. Narud, A. Pandiscio and B. Henning.

Objectives The first part of this project endeavors to study the properties of nonlinear feedback systems governed by equations of the form :

$$a\frac{dy}{dt} + \frac{by + c - f(y)}{1 - \frac{1}{b}\frac{df(y)}{dy}} = 0 \tag{1}$$

$$m\frac{d^2y}{dt^2} + [a + j(y)]\frac{dy}{dt} + by + c - f(y) = 0, \tag{2}$$

and this application to:

1. Vacuum tube circuits
2. Transistor circuits
3. Various forms of nonlinear servo-mechanism systems.

To the above expressions

$$f(y) - by - c = 0$$

represents the steady-state equation of the system and

$$1 - \frac{1}{b}\,\frac{df(y)}{dy}$$

the nonlinear return difference function.

Status A report has just been written up on the application of this study to the analysis of memory devices and another is being written up on the properties of a circuit having a monostable and unstable mode of operation.

Some of the results of this study are being utilized in a generator producing electronically generated pulses having a width of 20 mμs. Tests made so far on this device indicate an agreement with theory of about 20 per cent. When this generator has been perfected it will be described in another report.

Mr. A. Pandiscio, who is doing his thesis on this project, is going to make a study of nonlinear systems in which the transfer function is a function of time as well as magnitude. The results of this study will be applied to various transistor pulse circuits. Mr. Pandiscio is presently building up equipment for investigation of the time dependence of transistor characteristics.

Mr. B. Henning who is also doing his thesis on this project is working on a theoretical study of the properties of nonlinear systems having multi-order and complex operating points.

I-F-2 Zeros of Noise, G. M. White.

Objective To study the zero-crossings of random noise.

Practical Significance The results of this series of experiments may improve the techniques of detecting FM signals in noise.

Status The noise generator has been built, using a shot noise tube and several stages of amplification. A filter giving a power spectrum of $1/1 + (\frac{\omega}{\omega_o})^4$ and $1/[(\frac{\omega}{\omega_o})^4 + a(\frac{\omega}{\omega_o})^2 + b]$ $(\omega_o = 10^4)$ has also been attached. G. Fellows' spectrum-analyzer is being modified to measure a 5-cycle band of noise anywhere from 2 to 20,000 cycles. Then the spectrum of the noise generator will be accurately measured to see that it has the desired spectrum.

I-F-3 Insertion-loss Filters, Y. F. Chang.

Objective Investigation of methods of designing insertion-loss filters with lossy elements.

Practical Significance — The present methods of designing filters are all based on the assumption that lossless circuit elements are obtainable. The result is that the designed filters do not necessarily meet the specifications.

Status — Study of the literature in this field continues.

I-F-4 Potential Analog, Y. F. Chang.

Objective — Design and construction of a conducting-paper potential analog with positive and negative constant-current probes and associated power supplies.

Practical Significance — This potential analog is useful in network synthesis, where the positive and negative constant-current probes are the respective poles and zeros of the transfer function.

Status — Construction of the apparatus is nearing completion.

II

ELECTRON AND SOLID-STATE PHYSICS

Academic Staff: Prof. J. H. Van Vleck
Prof. H. Brooks
Assoc. Prof. N. Bloembergen
Dr. F. K. Willenbrock

II-A Radio and Microwave Spectroscopy of the Solid State

A considerable number of coordinated investigations of nuclear and electronic spin resonance in various types of solids are intended to result in a better understanding of the structure and behavior of magnetic spin systems and of the nature of crystalline imperfections in solids.

II-A-1 Nuclear Magnetic Resonance in Alloys, D. Weinberg.

Objective To obtain information about the electronic structure of alloys by studying line-shape, width, shift, and quadrupole effects as a function of concentration of the solute metal, magnetic field strength and isotopic constitution.

Status New measurements have been made at 6.2 Mc/s on freshly quenched aluminum-zinc alloys of eight compositions. These agree with Rowland's results at intermediate concentrations, but give a lower intensity at 6.4 atomic per cent zinc, which is tentatively attributed to local strain incurred in quenching. The decrease in line width with increasing Zn content is qualitatively confirmed.

X-ray powder patterns show definite room temperature precipitation in a 5.0 atomic per cent zinc specimen. The X-ray method will be applied to determine the effect of low-temperature annealing.

II-A-3 Nuclear Magnetic Spin-Spin Relaxation, K. Dwight.

Objective To measure spin-spin relaxation times in systems of nuclear magnetic dipoles when energy is absorbed at audio frequencies in weak external magnetic fields.

Status Saturation measurements on the CaF_2 crystal showed the calibration circuit to be faulty. The error was traced to the injection of the audio frequency directly onto the input grid of the oscillator tube, and was corrected by inserting an RC filter in the tank circuit between the calibration input and the oscillator. The crystal was then found to be unsaturated at room temperatures at the lower r-f levels attainable.

A shortage of vacuum pumps necessitated both revision of one of the existent pump systems and improvement of the metal dewar, which was remade so as to hold a satisfactory vacuum for several weeks without pumping. It was discovered that the inside joint between the stainless-steel tail and its brass end-plug opened up at liquid nitrogen temperatures, due to the very appreciable difference in thermal expansion between the two metals. This fault was temporarily cured by resoldering the joint with great care, but it may prove necessary to replace the stainless-steel tube with a brass one.

Subsequent measurements at liquid nitrogen temperatures demonstrated a very unsatisfactory signal-to-noise ratio. The excessive noise was due to the frequency modulation of the coil by the bubbling of the liquid nitrogen. Present efforts are being directed toward minimizing this difficulty by embedding the coil and its lead wires more securely, so as to eliminate the nitrogen from the immediate vicinity of the coil.

II-A-4 Chemical Shift of the Nuclear Resonance in Solids, P. Sorokin.

Objective To measure the shift in the nuclear resonance frequency due to the orbital motion of electrons and to explain the observed phenomena theoretically.

Status The chemical paramagnetic shift σ was measured in a number of alkali-halide samples. For some of these samples there had been previous measurements of σ reported [1, 2]. Those values of σ not previously reported were measured to be:

$$\sigma = (-5.0 \pm 0.3) \times 10^{-4} \quad \text{for } I^{127} \text{ in CsI}$$
$$\sigma = (-2.5 \pm 0.3) \times 10^{-4} \quad \text{for } Br^{79} \text{ in CBr}$$
$$\sigma = (-1.7 \pm 0.3) \times 10^{-4} \quad \text{for } I^{127} \text{ in RbI}$$

Other values of σ for the bromides and iodides were determined for KI, NaI, KBr, and NaBr and these were in agreement with Kanda's results within experimental error. The values obtained were

$$KI = (-1.0 \pm 0.3) \times 10^{-4}$$
$$NaI = (-1.2 \pm 0.3) \times 10^{-4}$$
$$KBr = (-.22 \pm 0.2) \times 10^{-4}$$
$$NaBr = (+.58 \pm 0.3) \times 10^{-4}$$

Runs were made on the Na^{23} resonance in NaI, NaBr, and NaCl · NaI showed a slight paramagnetic shift ($-.3 \times 10^{-4} \pm 0.3$) but there was no detectable

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1. Gutowsky and McGarvey, J. Phys. Chem. 1953.
2. T. Kanda, J. Phys. Soc. (Japan) February 1955.

shift in NaBr or NaCl.

To see if Gutowsky's and McGarvey's results on the Cs^{133} chemical shift could be reproduced, runs were made on CsI, CsBr, and CsCl. In these samples the center frequency was determined by sweeping through the resonance curves from the high-field side and from the low-field side and then averaging the frequencies at which the peaks of the transient response curves occurred. The values of σ obtained were (in agreement with Gutowsky's results):

$$\text{CsI} \quad \sigma = (-2.5 \pm 0.4) \times 10^{-4}$$
$$\text{CsBr} \quad \sigma = (-1.9 \pm 0.4) \times 10^{-4}$$
$$\text{CsCl} \quad \sigma = (-1.7 \pm 0.4) \times 10^{-4}$$

The Harshaw single crystals of CsI and CsBr gave only transient absorption mode responses because of the long relaxation time T_1, which appeared to be about 10 minutes at room temperature in a field of 5,500 gauss. This is not surprising since Cs^{133} has a known quadrupole moment of $-(.003 \pm .002) \times 10^{-24}$ cm^2, which is very small [3]. Work is in progress on a free induction T_2 measurement of the Cs^{133} resonance in CsI in order to determine the effects of the nuclear spin exchange on T_2 in this crystal. Since T_1 is so long, even at room temperature, and since the experiment will be done at 77°K, it is not necessary to use pulse techniques to bring the magnetization M into the x-y plane. The estimated signal-to-noise ratio appears to allow an oscilloscope display of the decay signal. Also planned is an attempt to follow the variation of the chemical shift σ of the I^{127} resonance in CsI with temperature from 20° to the melting point of the crystal (620°C). This crystal has the largest chemical shift of the alkali-halides and at room temperature a good signal-to-noise ratio was obtained for it.

If the I^{127} line becomes too broad because of quadrupolar lifetime broadening at higher temperatures the Cs^{133} resonance will be looked at. If the variation of σ could be observed near the melting point, one could check the validity of the molecular model which appears to account qualitatively for the chemical shift [4]. Measurement of T_1 near the melting point may give information about vacancy diffusion. A high-temperature n.m.r. probe has been built.

II-A-5 Nuclear Magnetic Resonance in the Alkali Metals under High Hydrostatic Pressure, G. Benedek, T. Kushida.

Objective: To study the pressure dependence of the Knight shift and the relaxation times in the alkali metals from 1 to 10,000 kg/cm^2.

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3. K. Althoff, Z. Phys. 141, p. 33, 1955.
4. Yosida and Moriya, J. Phys. Soc. (Japan) January 1956.

Status Measurements of the pressure dependence of the Knight shift have been carried out in metallic lithium using techniques similar to those in the case of sodium reported in Progress Report No. 38. It was found that at 9.781 Mc/s the resonance frequency in metallic lithium decreases by 35 cps $\pm$ 15 cps for 10,000 atmos. applied pressure. This corresponds to a change in Knight shift of (1.4 $\pm$ .6)% to 10,000 atmos. Using Bridgman's compressibility data the experimental results can be described by

$$\frac{\Delta\nu}{\nu} = .000249 \left(\frac{V}{V_o}\right)^{.18\pm.08}$$

over the entire pressure range. If one determines from Pines' collective electron model [1] the volume dependence of the susceptibility, including Brooks' calculated [2] dependence of m* on V one finds that the deduced volume dependence for P_F is $P_F = .125(V/V_o)^{.21\pm.08}$. On the other hand, if one uses a free-electron picture one decides $P_F = .193(V/V_o)^{-.03\pm.08}$. The smallness of the observed change in lithium has stimulated an effort, now in progress, to increase the over-all accuracy of the frequency determination which is now about 1.5 parts per million.

II-A-6 The Influence of Hydrostatic Pressure on the Pure Quadrupole Resonance, G. B. Benedek, N. Bloembergen, T. Kushida.

Objective To measure the pure quadrupole resonance frequency as a function of pressure in the range 1 to 10,000 kg/cm^2.

Status Since the last report, measurements of the pressure dependence of the pure quadrupole resonance frequency have been made in $KClO_3$ at 25°C and in Cu_2O at -69°C and 98.5°C. In $KClO_3$ $1/\nu(d\nu/dP)_T = 1.02 \times 10^{-6}$ at the lower pressures. At pressures around 4000 atmos., $1/\nu(d\nu/dP)_T$ begins to decrease, until near 9000 atmos., it is reduced to half its initial value. In Cu_2O, $1/\nu(d\nu/dP)_{T=-69^oC} = 1.44 \pm .02/\text{kg/cm}^2$ and $1/\nu(d\nu/dP)_{T=98.5^oC} = 1.38 \pm .02/\text{kg/cm}^2$. Work is now being carried on to relate these results with a theory in which the pressure variation is conceived as coming from a pressure-induced change in the magnitude of the internal field gradient and in the amplitude of the lattice vibrations.

II-A-7 Acoustical Quadrupole Saturation in Crystals, E. F. Taylor.

Objective To induce quadrupole transitions between nuclear spin levels by ultrasonic vibrations and to obtain detailed information about the relation between crystalline deformations and quadrupole interaction.

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1. Seitz and Turnbull, <u>Solid State Physics</u>: <u>Advances in Research and Applications</u>, Academic Press Inc., 1955.
2. H. Brooks, Private communication.

Status Most of the present period has been taken up with design and construction of equipment and with trouble shooting on equipment recently completed. The construction of an ultrasonic transmitter amplifier to set into ultrasonic resonance a cylindrical single crystal rod of the salt under investigation and an ultrasonic receiver amplifier to detect this condition of resonance was completed. Considerable time was spent eliminating oscillations in the transmitter amplifier, improving its gain, and isolating the transmitter and receiver amplifiers.

Cylindrical single crystal rods of NaCl one centimeter in diameter and of two different crystallographic orientations have been obtained and the ends ground fine to be perpendicular to the axes of the cylinders. Experiments with these single crystal rods show that the Pound rf spectrometer can detect the sodium line without saturating it. Ultrasonic transmitting and receiving quartz crystals have been received. The plating of electrodes and the cementing of the quartz crystals onto the ends of the NaCl rods is under way. A nuclear resonance head to support an NaCl rod between the poles of the magnet while shielding electrically the ultrasonic transmitting quartz crystal from the receiving quartz crystal and from the nuclear resonance coil has been designed and is under construction.

II-A-11 Determination of the F-center Oscillator Strength in Alkali Halides, R. H. Silsbee.

Objective To determine the oscillator strength of the F-band absorption in alkali halides by comparison of paramagnetic resonance and optical absorption data.

Status This project has been completed. Technical Report No. 221 has been issued and an article is being prepared.

II-A-12 Relaxation Effects of Electronic Spin Systems at Low Temperatures, S. Shapiro.

Objective To saturate one or more electron spin transitions in certain paramagnetic crystals and to observe Overhauser-type effects on other spin transitions in the same crystal.

Status Temporarily inactive.

II-A-13 Paramagnetic Resonance in Irradiated Crystals, S. Shapiro.

Objective To determine through a study of their magnetic properties the nature of metastable states produced in certain crystals by γ-ray or reactor radiation.

Status Paramagnetic resonance absorption has been observed at $77^{o}K$ in a single crystal of α-corundum (Al_2O_3) which had been irradiated with 100,000 roentgens of Co^{60} γ-rays. Investigation of this and other crystals* as a function of crystal orientation at liquid helium temperatures is in progress.

II-A-14 Electronic Spin Resonance Experiments under High Hydrostatic Pressure, W. M. Walsh, Jr.

Objective To study the possible variation of g-factors, line widths and structure of paramagnetic resonance spectra under the influence of hydrostatic pressures up to 10,000 atmos.

Status A coaxial transmission-line section suitable for introduction of X-band frequencies into a nonmagnetic high-pressure bomb has been designed and tested in preliminary form. A T.E.M. mode test cavity which fits in an existing high-pressure bomb has been built and measurements of the Q-factor and degree of coupling to the transmission line are in progress.

II-A-20 Ferromagnetic Resonance in Single Crystals of Nickel Ferrite, C. J. Hubbard.

Objective To obtain the ferromagnetic anisotropy constants, g-value spin-spin and spin-lattice relaxation times (T_1 and T_2) in nickel ferrite in the temperature range from 300°K to 1.6°K.

Status High-power ferromagnetic resonance measurements have been made at 4°K on the same single crystal of nickel ferrite used by Wang (T.R. No. 188).

The absorption line is 50 per cent saturated at a power level of $H_1^2 \sim 0.1$ oersted^2, as contrasted to 20 oe^2 found by Wang at 300°K and 7 oe^2 at 77°K.

The magnetic relaxation (decay of M_z) is observed to take place in less than 2×10^{-7} sec, but precise measurements have not yet been made.

II-A-21 Ferromagnetic Resonance in a Single Crystal of Nickel, K. H. Reich.

Objective To obtain the ferromagnetic resonance line-width in a single crystal of nickel and its magnetic anisotropy constants at various temperatures down to 1.6°K, at frequencies in the 3 cm and 1 cm regions.

Status This project has been terminated and a technical report will be issued. (See also Phys. Rev., March 1956.)

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*The crystals were furnished by Dr. P. W. Levy of Brookhaven National Laboratory, who has studied their optical absorption.

II-B Properties of Electrons in Solids

Several investigations, using widely different experimental techniques, are all concerned with the behavior of electrons in metals and semiconductors. They include the measurement of Hall effect in ferromagnetic materials, electronic spin specific heat, magnetoresistance and properties of semiconductors under hydrostatic pressure.

II-B-1 Hall Effect in Ferro- and Ferrimagnetics, J. Lavine.

Objective — To investigate some of the electrical and magnetic properties of ferrites by means of the Hall measurement. The purpose of the measurement is to obtain information about the conductivity mechanism in ferrites.

Status — This project is terminated. Technical Report No. 225 is in press.

II-B-2 Specific Heats of Solids at Low Temperatures, E. Weiss.

Objective — To study the specific heat of ferrites and alloys at liquid-helium temperatures.

Status — Results of a repeat run made on the same copper sample used by Kouvel in his last run checked very well with that run. The specific heat results also checked well with the curve (and equation) given by Squire [1] in the higher-temperature region (about 3.5°K), with deviation from Squire's data increasing slowly with decreasing temperature.

A first attempt to prepare a brass sample by induction heating resulted in a sample with much segregation. Another attempt is in progress.

II-B-3 Magneto-resistance in Strained Metals, C. W. Maynard.

Objective — To investigate the change in resistance of metals at the temperature of liquid helium when subjected simultaneously to a magnetic field and to a strain.

Status — During the past quarter a number of sets of data have been taken on germanium and silicon samples. The results obtained have been reduced to an experimental quantity d, given by

$$d = \frac{\{R(x, H) - R(o, H)\} - \{R(x, o) - R(o, o)\}}{R(o, o)} ,$$

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1. Low-Temperature Physics.

where R(x, H) is the resistance measured in the presence of stress x and magnetic field H. Thus d represents the difference between the piezoresistance with and without a magnetic field present. It is expected theoretically that d will be linear in the stress x and an even function of the magnetic field (the quadratic term being the most important for low fields).

On plotting experimental values of d versus the stress x, it is found to be linear as expected and the variation of d with magnetic field is at least qualitatively correct. However, these results have not been reproducible to a desirable degree. Reasonably good curves are obtained from data for a single experimental run, but curves taken under the same conditions on different days are different.

Difficulties have also been encountered in making good electrical contacts to the samples at low temperatures. Use of ultrasonic soldering technique usually gives good contacts; however, these break off beneath the solder joint on being taken several times to liquid nitrogen temperature. Presumably, this is due to the thermal strain cycles.

Further effort will be made to improve the reproducibility of the results. The problem of making good low-temperature contacts is still being investigated.

II-B-4 Properties of Semiconductors under Pressure,* W. Paul, H. Brooks.

Objective — To investigate the electric, magnetic and optical properties of semiconductors at pressures up to 30,000 kg/cm^2.

Status — Parts of this project are being carried out in collaboration with Group 35, Project Lincoln, at M.I.T. Extensive use is being made of the facilities available in Professor Bridgman's laboratory.

a. Measurement of Hall Constant and Magnetoresistance

Nothing to report for this period.

b. Measurement of the Optical Properties**

A 300 line/mm grating having a linear dispersion of 179 mm/micron in second order has been installed in our monochromator. The grating dispersion

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*This is a coordinate program largely supported and partially staffed by Lincoln Laboratory.

**In conjunction with D. M. Warschauer of Group 35, Lincoln Laboratory.

in this order is ten times larger than that of a glass prism at 1.5 microns and will thereby allow us to remeasure the small pressure shift of the absorption edge in silicon with greater accuracy.

The absorption spectra of a number of Ge-Si alloys have been measured at hydrostatic pressures up to 8,000 kg/cm^2. Germanium-rich alloys show a change of the energy gap with pressure quite similar to that of pure germanium, while the silicon-rich alloys exhibit behavior more like that of pure silicon than that of germanium. The change-over in the types of behavior, which are quite different [1], gives indirect confirmation of the picture of the energy band structure of Ge-Si alloys suggested by Herman [2], and of the pressure behavior of the conduction band minima involved as suggested by Paul and Brooks [3] and by Herman. A paper on these alloys will be presented at the April 1956 meeting of the American Physical Society.

Two short papers [4] have been prepared on apparatus and experimental techniques. One deals with an improved method of making vacuum-tight infra-red windows for use with liquid helium, while the other is on the application of flexible small-diameter tubing in high pressure work.

c. Measurement of Drift Mobility of Electrons and Holes in Germanium, A. C. Smith

Contacts were welded to an n-type crystal by passing a current of 0.8 amp through a .002" Ga-doped Au wire resting on the crystal. These contacts were found to be satisfactory for making mobility measurements, and reproducible results in good agreement with published results were obtained. The probable error in this method is about + 5 per cent with an additional uncertainty in the temperature. In view of the small expected change in hole mobility with pressure, the determination of mobility under pressure has not been attempted.

Similar welded contacts on a p-type crystal using Sb-doped Au wire were found to be unsatisfactory for mobility measurements due to their nearly ohmic character. An investigation of other methods of obtaining permanent contacts is in progress.

II-C Topics in the Theory of the Solid State

This program includes a number of subjects in the quantum theory of solids, many of which are closely related to the experimental program and supplement it. The various investigations include the theory of the cohesive energy and elastic constants of metals, the theory of impurity and imperfection wave functions in semiconductors and metals, and the theory of electrical resistivity as a function of pressure in metals.

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1. Warschauer, D. M., W. Paul and H. Brooks, Phys. Rev. 98, 1193(A) (1955).
2. Herman, F., Phys. Rev. 95, 847 (1954).
3. Paul, W. and H. Brooks, Phys. Rev. 94, 1128 (1954).
4. Submitted to Rev. Sci. Instrum. for publication.

Cohesive Energy of the Monovalent Metals

Dr. Ham, now with the General Electric Research Laboratory, has been recalculating the polarization correction for the alkali metal using the first-order perturbation theory method instead of the WKB method. The results indicate that there are appreciable differences between the two methods, and it is our present feeling that one could use the polarization correction only to set upper and lower bounds for the cohesive energy. The calculation without the polarization correction gives the greatest cohesion, and the polarization correction probably overestimates the changes. This matter is being investigated further. The conclusions stated in Progress Report No. 38 that the improved calculations do not significantly alter the values of the cohesive energy still stand. At present, calculations are under way with a smaller interval for the cell radius, so that better curves of cohesive energy vs. lattice constant will be available. (H. Brooks)

Resistivity of the Alkali Metals

A program is being set up for machine calculations on the theory of the resistivity of alkali metals, discussed in P. R. No. 38. This program involves numerical solution of the Born secular equation for the lattice vibrations, and the carrying out of suitable averages over direction in order to obtain matrix elements for the resistivity both at low and high temperatures, which take into account the elastic anisotropy and the dispersion. The program is being extended to include the electronic contribution to thermal conductivity and the thermoelectric power as well as electrical resistivity, since the extra computation involved is relatively minor.
(M. Bailyn, H. Brooks)

Magnetic Properties of Conduction Electrons

A numerical error was found in the earlier computation of $|\psi_k(o)|^2$ for Na, which makes the theoretical value with the Quantum Defect method about 14 per cent higher than the best experimental result, and also than Kohn's calculation. Recently, Dr. Ham at General Electric has completed a calculation of $|\psi_A(o)|^2$ for the lowest free atom state, using the Quantum Defect method on the IBM 650. The value is considerably higher than that given by Kohn, with the result that the theoretical value of P_F/P_A is only about 6 per cent too high. The reasons for the discrepancy with Kohn's calculations are now being sought. It could be a result of the approximate nature of the potential used by Kohn, or it could be the result of errors in the WKB method used in the present calculation. It can be shown that the errors in the WKB method as applied to this problem are relatively of the same order of magnitude as the error in computing the free-atom eigenvalues from the assumed potential by the WKB method. (H. Brooks)

Semiconductory Theory

Further work has been done on the theory of impurity states in semiconductors, a project which has been relatively inactive since Dr. Fletcher's departure last September. It has been found possible to construct quite a general variational formulation of the boundary condition on the surface of the impurity cell. This variational formulation turns out to be rather a straightforward generalization of Kohn's first variational method for periodic lattices. [Phys. Rev. 87, 472 (1952)]. The result is that the following functional is stationary:

$$J(E,\psi) = \mathrm{Re}\int \psi^*(H-E)\psi d\tau + \mathrm{Re}\int (\psi_i \frac{\partial\psi^*_o}{\partial n} - \psi^*_o \frac{\partial\psi_i}{\partial n})dS$$

with respect to arbitrary variations in the wave function ψ_i and ψ_o on the boundary as well as in the interior of both regions. Here ψ_o and ψ_i are the values of the interior and exterior wave functions respectively on the boundary between the impurity cell and the rest of the lattice. If the energy parameter is adjusted to make the boundary integral vanish, then it can be shown that the resultant E is stationary. To a large extent this result merely justifies on a mathematical basis the approximate forms of boundary conditions used by Fletcher in his work on donors in silicon, and also to some extent justifies the approximation used by Kohn and Luttinger [Phys. Rev. 98, 915 (1955)] in their work on the hyperfine splitting of donor levels in silicon. However, the variational formulation does result in certain refinements in the boundary conditions which should give improved estimates of the energy. These have not yet been exploited. (H. Brooks)

Work continues on the theoretical study of intervalley scattering in germanium and germanium-silicon alloys. A rather straighforward extension of the theory to cover the galvanomagnetic properties has been made. This theory has turned up some definite discrepancies between theory and experiment which cannot be explained away by any simple variations of parameters. For example, the theory predicts that the Hall mobility should show a slight increase with pressure in pure germanium in the low pressure range, whereas actually a decrease is observed. Also, the longitudinal magnetoresistance in the (100) direction cannot be properly explained. It has also been realized recently that primarily owing to the extreme sensitivity of the (000) minimum to pressure, there should be a fairly large pressure coefficient of the dielectric constant in germanium. This in turn implies that considerable pressure variation of the ionized impurity scattering should be observed as in fact it is. Pressure variation of the ionized impurity scattering cannot be explained in any other simple way since this scattering is relatively insensitive to the effective mass, and furthermore it can be shown that intervalley scattering with ionized impurities is relatively improbable, because most of the scattering involves very small momentum changes. Great importance thus attaches to a more precise measurement of the position of the (000) minimum relative to the valence band as a function of pressure and to measurements of the dielectric constant. (M. Nathan, H. Brooks)

II-D

Electron Physics

II-D-1 Surface Properties of Germanium and Silicon under Ultra-High Vacuum, A. Fowler.

Objective: To study the surface properties of germanium and silicon under the very clean conditions afforded by ultra-high vacuums.

Status: Measurements were made on the variation of contact potential with crystal face on a p-type sample and, contrary to expectations, the result differed from that for the n-type. The data below represent the deviation of the germanium work function from the average of the six faces measured and are an average for 18 runs with an error of about 8 mv. Allen's data for an n-type sample are given for comparison:

Face	p-type	n-type (Allen) clean	n-type (Allen) contaminated
(100)	0 ev	.038 ev	- .032 ev
(110)	.020	-.012	+ .058
(111)	-.020	-.026	- .026

There was little change in the p-type sample when exposed to 10^{-6} mm of oxygen. No light effect was observed for this sample. As already noted, these results are unexpected, and further study must be made before they can be accepted.

III

WAVE PROPAGATION

Senior Staff: H. R. Mimno
J. A. Pierce

Project III-1 Study of Ionospheric Abnormalities, J. A. Pierce, J. C. Williams

Objective In the study of upper-atmosphere characteristics, radio reflections due to the passage of meteors, the occurrence of auroral displays, and the presence of sporadic ionization are of considerable interest.

Status F-Region

A technical report (No. 233) on this project has been issued. The research is continuing with the taking of records at four receiving sites. These will be analyzed by project personnel when a sufficient number have accumulated.

Project III-3 An Oscillator of Unusual Long-Term Stability, J. A. Pierce

Objective Crystal oscillators of exceptional stability provides a simple method of maintaining synchronism between a distant pulse transmitter and a local recording oscilloscope for the study of long-distance propagation. For this purpose the local oscillator is adjusted manually with as much precision as possible to the same frequency as the distant oscillator. If the oscillators are sufficiently stable, they will not differ after a day or so by more than a part in 10^8.

Status There is nothing new to report.

Project III-4 Studies of Transmission Time and Absorption in an Atmosphere of Varying Refractive Index, Mrs. E. H. Moritz, J. A. Pierce

Objective The purpose is two-fold: (1) to improve current methods of eliciting from a vertical-incidence ionospheric sounding, information concerning oblique sky-wave transmission, such as maximum usable frequency, skip distance, etc., and (2) to utilize oblique-incidence relations in obtaining from the records of Project III-2 further information regarding electron distribution in the ionosphere and its effect on transmission time and sky-wave signal strength.

Status We have spoken a number of times about the stability of VLF transmission. This quarter, it seems appropriate to discuss some of the abnormalities occasionally observed. These studies seem to us to confirm the idea that we have, in fact, a new and useful technique for ionospheric studies.

An interesting, and apparently rare, geomagnetic disturbance occurred on the (local) night of February 22-23, 1956. It was characterized by an unusually sudden increase in cosmic ray activity, quoted in newspaper reports as beginning at $3^h\ 45^m$ Universal Time on February 23, and persisting for many hours.

Dr. Kurt Toman, of the U. S. Air Force Cambridge Research Center, has kindly investigated the data available to that organization. He reports privately that a solar flare, accompanied by a sudden inospheric disturbance, was observed at Tokyo at $3^h\ 3^m$ U. T. It is apparently not yet clear whether this S.I.D. was of unusual intensity.

With equal kindness, Dr. Alan Shapley, Chief of the Sun-Earth Relationships Section of the National Bureau of Standards, has written me that this was an unusual event in that exceptional absorption of radio waves was observed at ionospheric observatories in the auroral zone on the dark side of the earth. This absorption apparently began within an hour after the event and persisted for a day or two. Dr. Shapley reports the beginning of the increase in cosmic ray intensity at $3^h\ 50^m\ 30^s$ U. T.

Nearly simultaneous effects were observed here on a very low frequency transatlantic signal. Although this technique is relatively new, the effects in this instance are rare in the sense that nothing similar has been noted in substantially continuous observations that have extended over some 20 months.

The experimental technique involved records the received phase of the 16 kc/s carrier from Rugby, England, with respect to the phase of a standard oscillator at Cambridge, Massachusetts. A summary of the technique and a description of the normal diurnal variations have been given in earlier reports.

Although the first-order phase variations observed by this method are those caused by differences between the two sources of frequency, the use of very stable oscillators, plus care and good luck, has made it possible to measure the diurnal variations in transmission time with fair accuracy. The ordinary change from night to day is about 35 μsec in the transmission time, and individual normal days' records seldom show a deviation from the average of more than ± 5 μsec. There is, however, a tendency to exceed this deviation during nights of unusually high magnetic activity.

An alternative way of expressing the high stability of VLF propagation is in terms of doppler effects on the received frequency. These are caused by changes in height of the reflecting layer or by changes in the phase shift at reflection. In the average, there is no measurable doppler shift during the hours of daylight or darkness over the whole path. During the sunrise period (from the first incidence of solar rays on the first reflection point until about the time the sun is on the horizon of the last reflection point) the layer is falling and the received frequency is increased by about 2 parts in 10^9. Similarly a doppler shift of $-2/10^9$ is observed during the sunset period. Deviations from these values are usually less than 1 in 10^9, even over short intervals but, again, high magnetic activity at night may induce quasi-cyclic variations of 2 or 3 parts in 10^9.

The event of February 22-23 is unique in having produced a doppler shift of no less than $+65/10^9$, something like 20 times the magnitude of the normal maxima. The phase diagram for this event is the original record shown in the upper part of Fig. III-1. This record has a vertical breadth of approximately one period (62.5 μsec) of the carrier frequency. The dark and light bands shown are simply the positive and negative excursions of the carrier cycle. At the bottom is a normal record for a magnetically quiet night showing a little of the sunset slope at the left-and the beginning of the sunrise slope at the right-hand end. Beginning at about $3^h\ 45^m$ U.T. in the upper record is the phase anomaly presumably associated with the solar flare of $3^h\ 3^m$ U.T., February 23, and the concurrent increase in cosmic ray intensity. The deviation in phase has the sense of decreasing transmission time, or reduction in the equivalent height of reflection. If, for the moment, we regard these phase changes as simply caused by variations in height of reflection it appears that the drop of some 44 μsec corresponds to a reduction from the normal nighttime height to somewhat below the normal daytime height. As can be seen from Fig. III-1, or perhaps better from Fig. III-2, where these phase changes are replotted on a more convenient scale, the "height" failed to return to the nighttime value and became normal only when daylight had returned to the whole path. There is some indication, in either Fig. III-1 or Fig. III-2, that some kind of primary effect persisted for about three hours. Presumably this is the period over which the height of reflection was below the normal daytime level, although there is certainly no conclusive evidence to this effect. It should be realized that changes of a few μsec over several hours, such as the increase between 23^h February 22 and 03^h February 23, may be caused by oscillator vagaries.

Figure III-3 shows the detail of the phase variation near 4^h U.T., so far as it can be scaled from the record, and Fig. III-4 gives the doppler effect on the received frequency; which is, of course, the negative of the slope of Fig. III-3. On Fig. III-3, dotted lines with appended approximate equations serve to define the rates of change. Perhaps the most curious feature of this phenomenon is the parabolic way the phase departed from normal for no less than the four minutes from $3^h\ 43^m$ to $3^h\ 47^m$ U.T. This is best seen in the linearity of the curve of Fig. III-4 for this interval. In this respect this event differs from the normal daytime S.I.D., whose onset is often almost instantaneous, as will be shown in an example below.

The chronology of this event, as observed at 16 kc/s, at least, may be divided into five periods:

(a) $3^h\ 43^m$ to $3^h\ 47^m$. A smooth increase in the rate of change of phase, perhaps corresponding to the building up of the force applied to the reflecting layer. At 0347 the layer height is apparently falling at a rate of at least one kilometer per minute.

(b) $3^h\ 47^m$ to $4^h\ 35^m$. Continuing change in phase but at a decreasing rate that is approximately a negative exponential. This may correspond to a sustained applied force acting upon an atmospheric density exponentially increasing as the height of reflections decreases.

(c) $4^h\ 35^m$ to $6^h\ 40^m$. A slow return of the phase, but not extending appreciably above the normal daytime level. The end of this period may indicate the time at which the applied force fell below that necessary to push the height of reflection below the normal daytime value.

(d) $6^h\ 40^m$ to $9^h\ 30^m$. Phase maintained at more or less the daytime value. This presumably indicates continuing incoming energy, at a lower level but still exceeding the ionizing energy normally available at night.

(e) After $9^h\ 30^m$. The effects of the phenomenon may have continued, but at a level so low as to be obscured by normal daytime ionization.

For purposes of comparison, examples of normal (daytime) sudden ionospheric disturbances are given in Figs. III-5 and III-6. The S.I.D. of March 15, 1956, shown in Fig. III-5, was of longer than average duration—an hour or more—but of relatively low intensity. On this occasion the 5 Mc/s signal from WWV (over a path of 650 km) was totally absorbed from $16^h\ 23^m$ to $17^h\ 30^m$ U.T., almost exactly the interval in which the phase diagram of Fig. III-5 shows appreciable curvature. Signals at higher frequencies, however, were less affected. For example, pulses recorded here from North Carolina (1300 km) at 9.1 Mc/s were barely perceptibly attenuated, and similar pulse signals at 12.9 Mc/s showed no effect whatever. The phase of the 16 kc/s signal from Rugby, Fig. III-5, was advanced by about 18 μsec, but shows no significant change in amplitude. It should be noted that, in contrast to the night-time phenomenon of Fig. III-1, the onset of the phase shift is very rapid.

The pattern with approximately four bars, at the left in Figs. III-5 and III-6, is a recording of the phase of the 60 kc/s standard frequency signal, MSF, also from Rugby, England. Because this transmission is made only from $14^h\ 30^m$ to $15^h\ 30^m$ U.T., and because GBR is shut down for maintenance between 13^h and 15^h, we use the same recording equipment for both signals

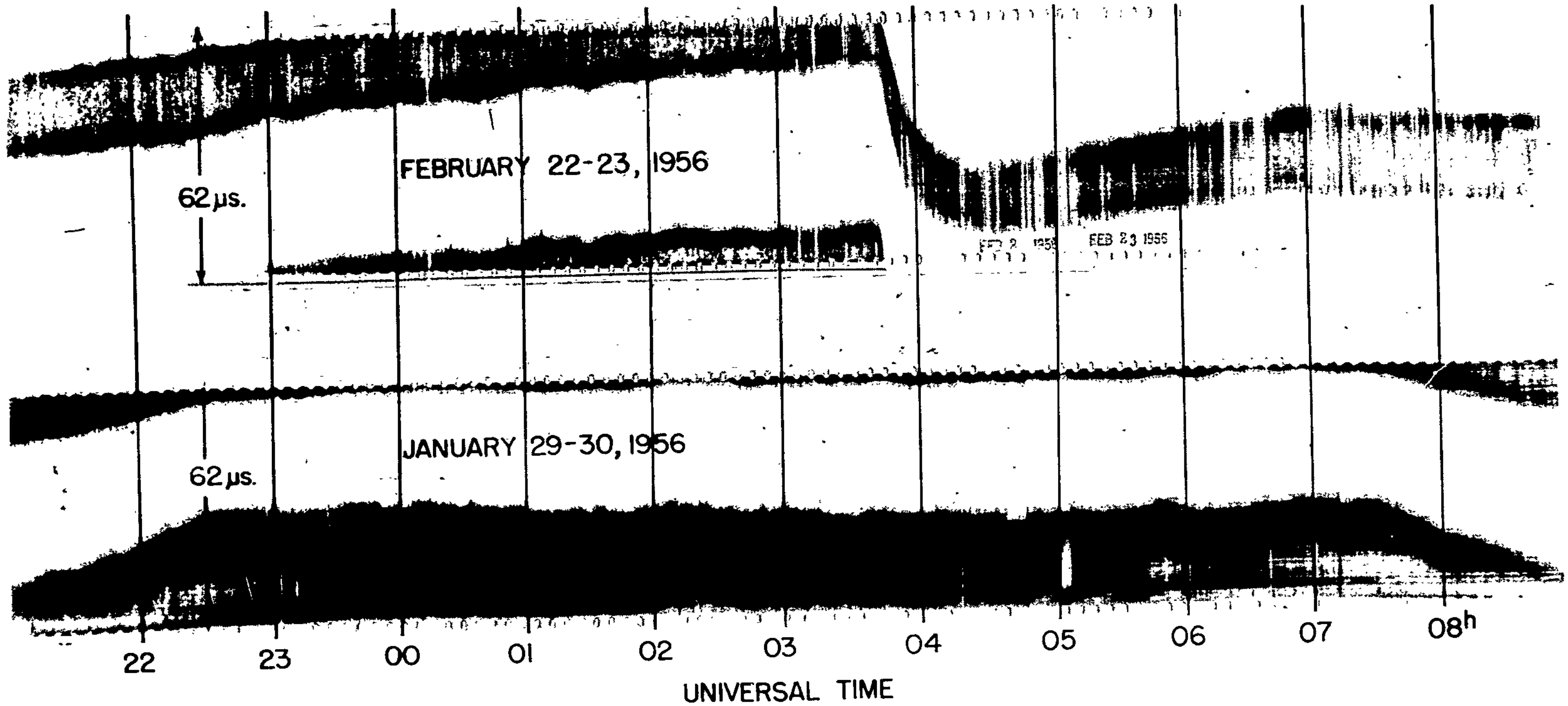

FIG. III-1 NIGHT-TIME VARIATION OF 16 kc/s PHASE AT 5200 km.
ABOVE: DURING ANOMALY OF FEB. 23, 1956.
BELOW: ON A SAMPLE QUIET NIGHT.

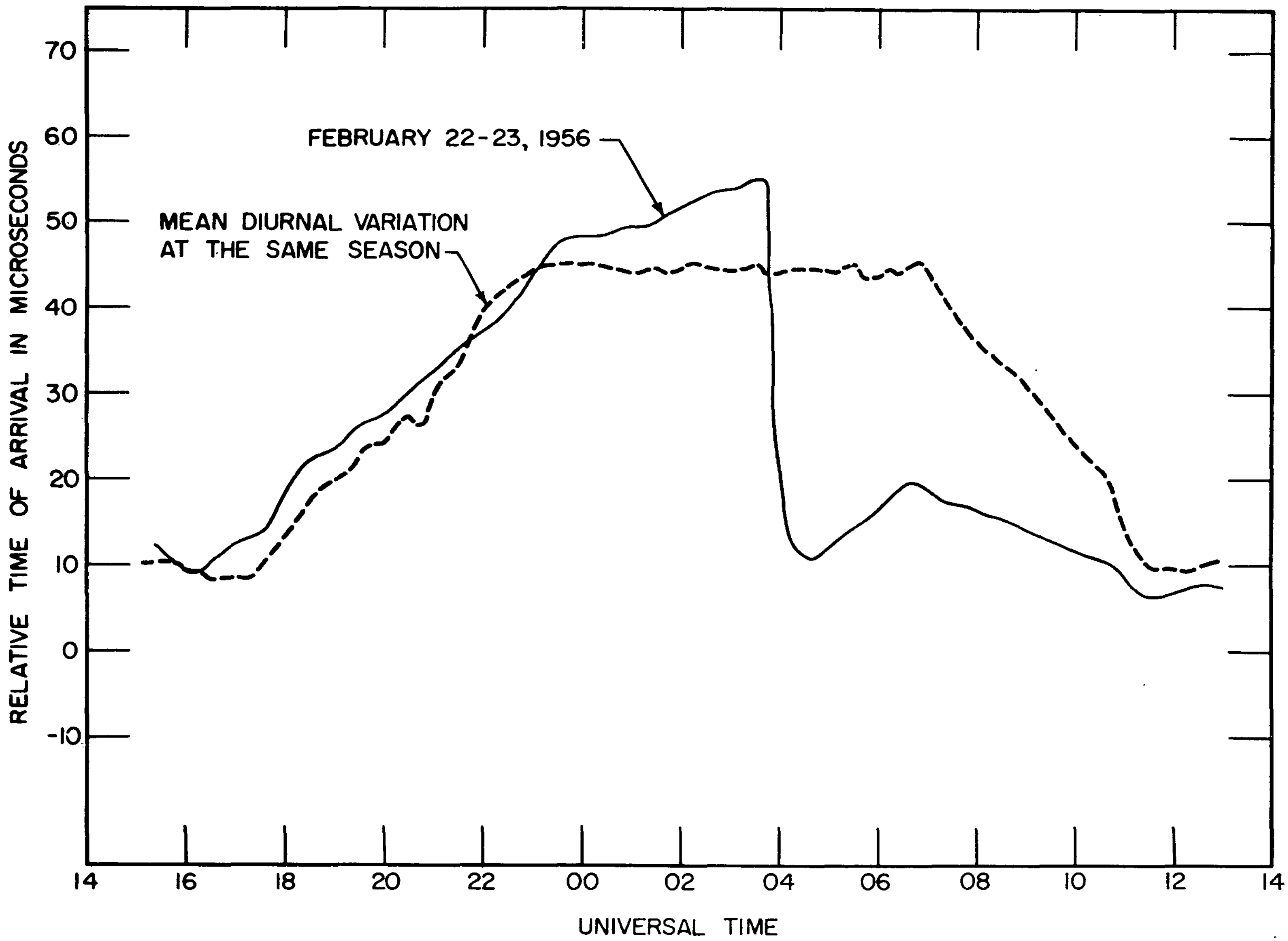

FIG. III-2 DIURNAL VARIATION OF 16 kc/s TIME OF ARRIVAL, FEB. 23, 1956

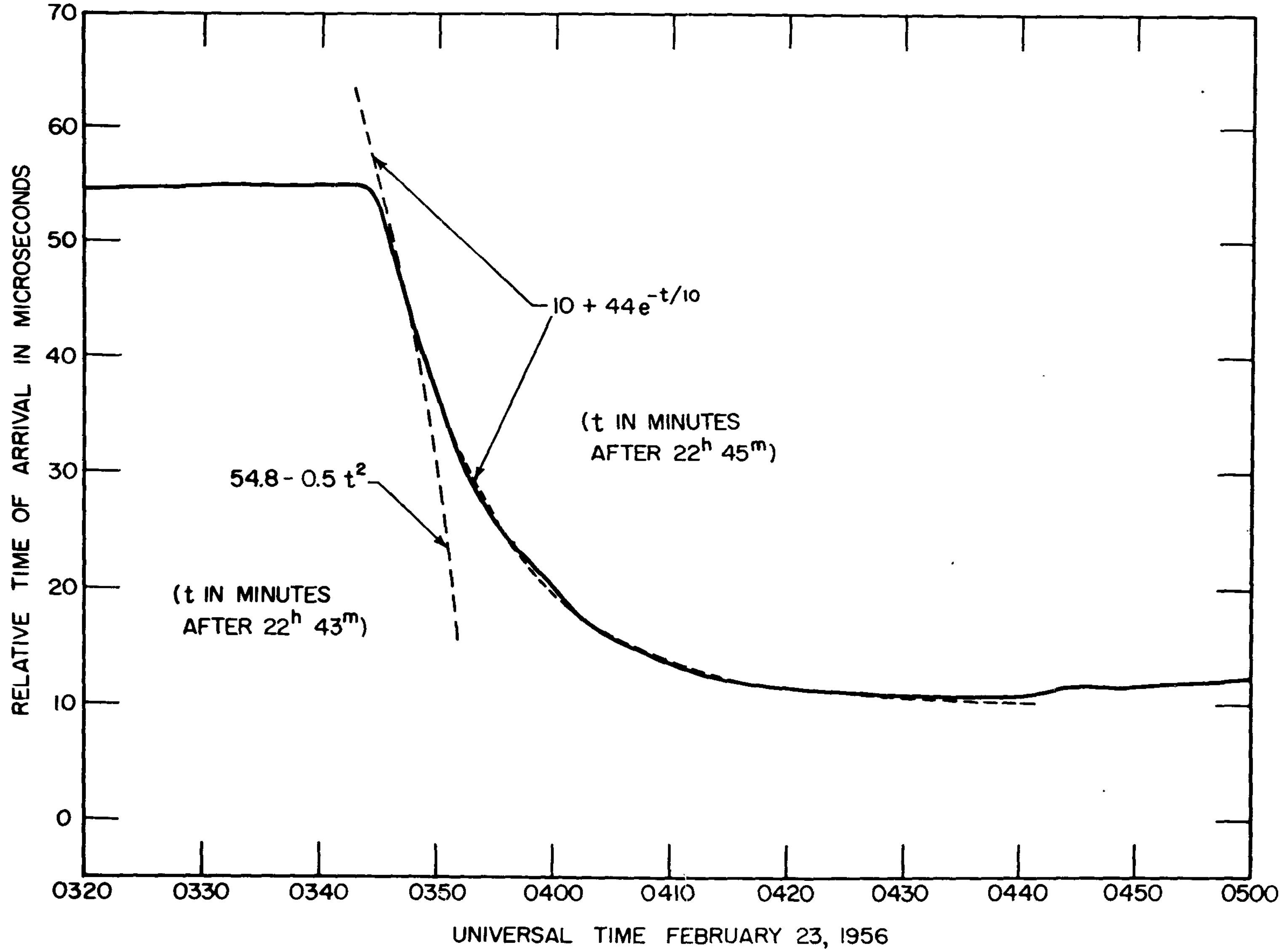

FIG. III-3 DETAIL OF THE ONSET OF THE SUDDEN REDUCTION IN TRANSMISSION TIME NEAR 4^h U.T. FEB. 23, 1956

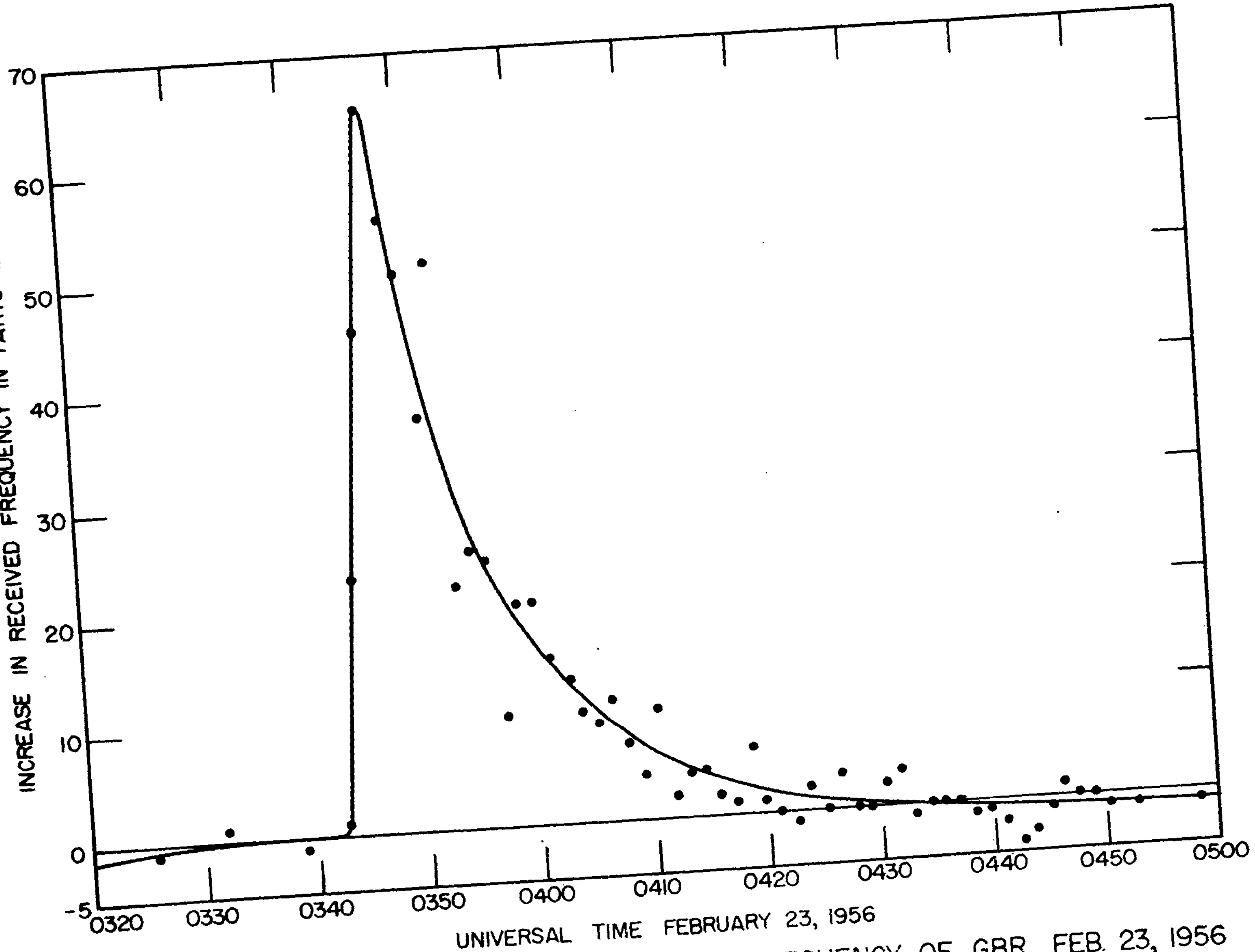

FIG. III-4 DOPPLER EFFECT ON THE RECEIVED FREQUENCY OF GBR, FEB. 23, 1956

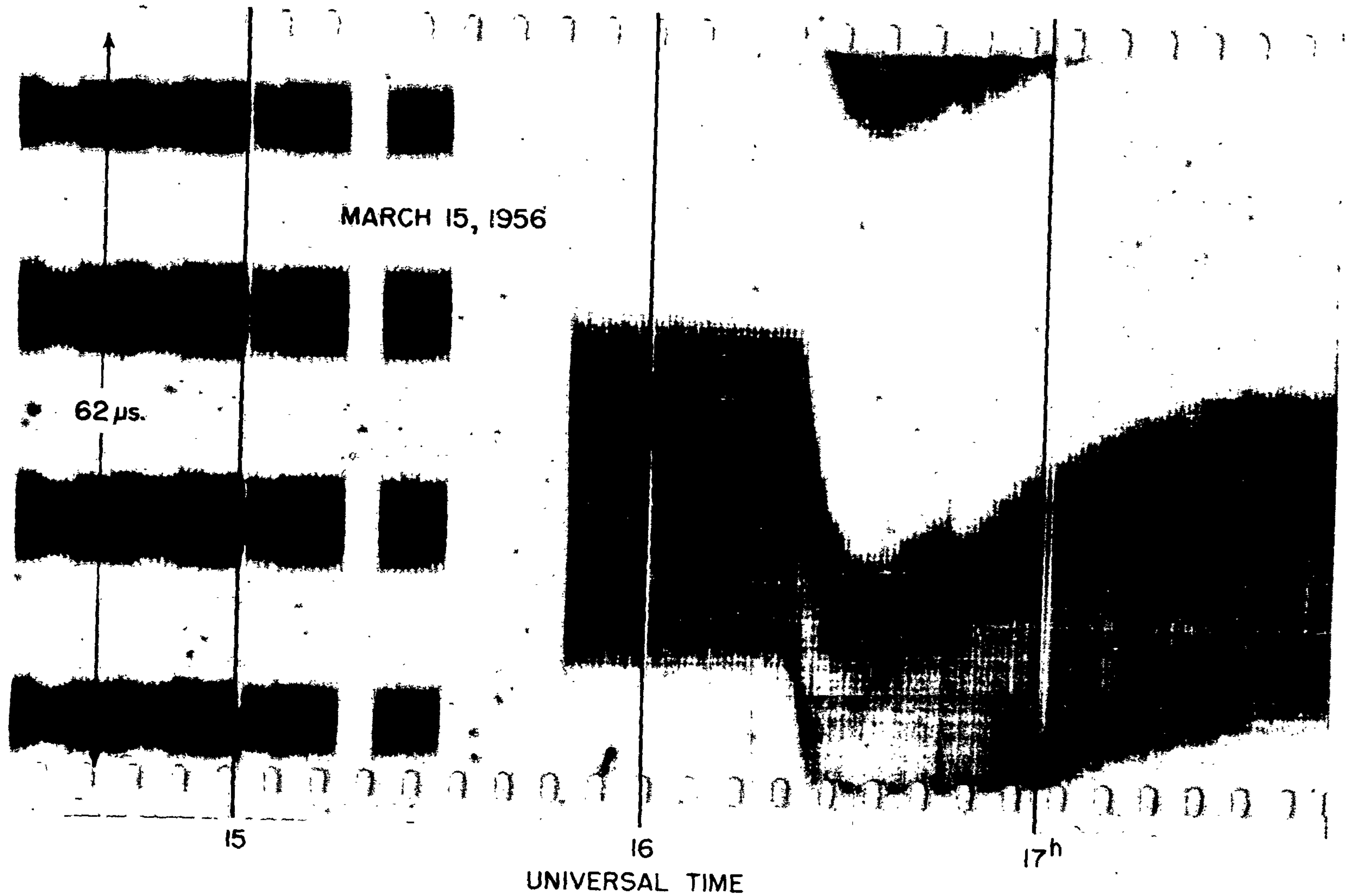

FIG. III-5 TYPICAL PHASE SHIFT, AT 16 kc/s, ASSOCIATED WITH S.I.D. AT 16^h 23^m MARCH 15, 1956

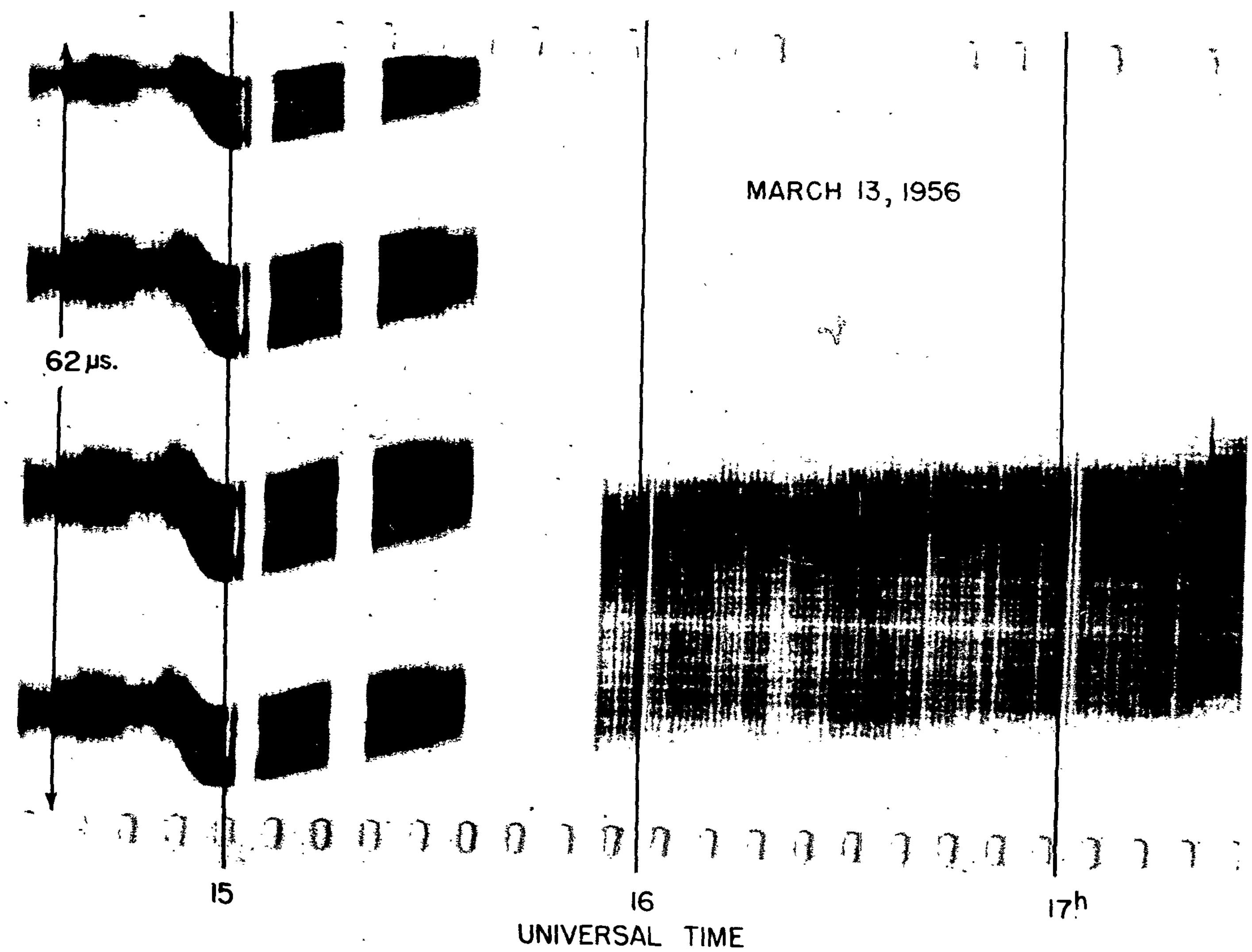

FIG. III-6 PHASE SHIFT, AT 60 kc/s, ASSOCIATED WITH S.I.D. AT $14^h\ 53^m$
MARCH 13, 1956

with a loss of only a small part of the GBR record.

Figure III-6 shows the phase shift produced by an S.I.D. that occurred while the 60 kc/s record was being made, at 14^h 53^m U.T. on March 13, 1956. In this case the S.I.D. was of shorter duration but greater intensity than that of Fig. III-5. The signals at 5 Mc/s, 9.1 Mc/s and 12.9 Mc/s, mentioned above, were all completely absorbed from 14^h 53^m to about 15^h 30^m U.T.

There are two interesting features in Fig. III-6. One is the indication of a considerable increase in amplitude of the signal, shown here by the broadening and blackening of the trace. This increase in field strength during an S.I.D. has often been reported at low frequencies. The effect, however, does not seem to obtain at VLF, as the amplitude of the signal at 16 kc/s in Fig. III-5, is sensibly unaffected.

The second interesting point concerns the small variation in phase during the S.I.D. observed at 60 kc/s. It will be recalled that this S.I.D. appeared to be more intense than that shown in Fig. III-5. The phase shift, however, in Fig. III-6, was only about 3.2 μsec or 70 degrees of phase, whereas the effect in Fig. III-5 was about 18 μsec, or 100 degrees of phase. This indicates that we must be careful about attributing these phase effects to simple changes in height of the reflecting layer. It is possible that, without much change in height, the primary physical phenomenon is a steepening of the ionization gradient with an accompanying change in the phase shift at reflection. In all probability, the effects we observe in Figs. III-1, III-5 and III-6 are a resultant of changes in both height and phase shift.

This new method of observation casts no light, at present, on the question of the height in the atmosphere at which these effects are produced. It is probable, however, that when this technique can be applied simultaneously to several radio frequencies it may yield new and valuable data.

Project III-5 Carrier-Frequency Phase Studies, J. A. Pierce, C. K. H. Tsao

Objective To exploit some of the possibilities of coherent detection at low radio frequencies. By utilizing the inherent phase stability of transmission at these frequencies, field strength can be measured well below the ambient noise level and new data on transmission time can be collected.

Status Construction of equipment continues.

Abstracts of Technical Reports

(Completed since January 1, 1956)

A High-Sensitivity Paramagnetic Resonance Spectrometer

R. H. Silsbee

Technical Report No. 221

A paramagnetic resonance spectrometer capable of detecting the order of 10^{12} spins at room temperature with a line width of one gauss is described. The report includes a description of the principles of operation of the spectrometer, details of its construction, and notes on auxiliary equipment used in conjunction with the spectrometer.

The Hall Effect in Ferromagnetic Metals and Semiconductors

Jerome M. Lavine

Technical Report No. 225

Hall measurements on Ni were made between room temperature and 568°C using an a-c measurement technique. The ordinary Hall coefficient of Ni is roughly constant between room temperature and 300°C. The data suggest that the extraordinary Hall effect persists into the paramagnetic region. The strong temperature dependence of the observed effect does not exhibit a temperature dependence similar to the susceptibility and hence there is ambiguity in the determination of the ordinary Hall coefficient above the Curie temperature. Hall measurements on a 70 Ni - 30 Cu alloy also suggest the presence of the extraordinary Hall effect above the Curie temperature, but in this alloy, the observed effect possesses a $1/T-\theta$ temperature dependence. The ordinary Hall coefficient of the 70 Ni - 30 Cu alloy is smaller in absolute value above the Curie temperature than at liquid air temperature. These data are discussed using Pugh's two-band and four-band models.

Hall measurements at room temperature were made on a synthetic crystal of Fe_3O_4 and on a synthetic single crystal of $(NiO)_{.75}(FeO)_{.25}(Fe_2O_3)$. The ordinary Hall measurement on Fe_3O_4 suggests that the number of conduction electrons at room temperature is large, in rough agreement with Verwey's hypothesis. The ordinary Hall coefficient of $(NiO)_{.75}(FeO)_{.25}(Fe_2O_3)$ also suggests a large carrier concentration. The conductivities of $(NiO)_{.75}(FeO)_{.25}(Fe_2O_3)$ and of a synthetic single crystal of $(NiO)_{.56}(ZnO)_{.14}(FeO)_{.30}(Fe_2O_3)$ are compared with the conductivity of Fe_3O_4 employing a simple model for the mobility and associating the activation energy obtained from resistivity data with the number of conduction electrons. The observed data are in good agreement with the simple model.

Extraordinary Hall measurements were made on Grade A Ni(99.4 Ni), 499 Alloy (99.9 Ni), and R-63 Alloy (95 Ni, 4 Mn, 1 Si) between liquid air temperature and their Curie temperatures, and on the 80 per cent Ni-Fe alloys, Supermalloy, Mumetal, and Carpenter Hymu 80 between liquid air temperature and room temperature. The extraordinary Hall coefficients of these materials do not generally exhibit the resistivity dependence predicted by Karplus-Luttinger theory, but they do suggest that the essential features of the theory are probably correct. The extraordinary Hall coefficients of Fe_3O_4 and $(NiO)_{.75}(FeO)_{.25}(Fe_2O_3)$ between - 100°C and their Curie temperatures indicate no resistivity dependence, and their magnitude, temperature dependence, and sign reversal have not been explained.

Auxiliary measurements of resistivity as a function of temperature, for all samples, and the thermoelectric power of Fe_3O_4 against Cu are also reported.

Electromagnetic Radiation over and into an Imperfect Dielectric

Seymour Stein

Technical Report No. 226

The electromagnetic fields are studied in relation to a vertical electric point dipole source located above a horizontal plane interface between two distinct but individually homogeneous media. A general saddle-point method of evaluation of the resulting integrals is used, leading to asymptotic (far-zone) results. Specific formulas are derived for the case where both media are "imperfect dielectrics" subject only to the lower medium being electrically denser, and computational results are presented for the specific case where the upper medium is air. Various ranges of the material parameters are considered and the corresponding changes in the character of the wave complex are shown to be related mathematically to the behavior of the singularities of the integrands. The transition to well-known limiting cases is also described.

Additional Reports Issued

January 1 — April 1, 1956

An Expansion of the Kummer Function ${}_1F_1(\alpha;\frac{1}{2};\beta x^2)$

Gordon Kent

Technical Report No. 234

Germanium Surface Potential Studies at High Vacuum

Frederick G. Allen

Technical Report No. 236

Field Emission from Germanium in a Müller Field Emission Microscope

Frederick G. Allen

Technical Report No. 237

Some Notes on High-Vacuum Apparatus and Techniques

Frederick G. Allen

Technical Report No. 238

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